GENERAL THORACIC SURGERY

VIDEO-ASSISTED THORACIC SURGICAL RESECTION WITH THE NEODYMIUM:YTTRIUM-ALUMINUM-GARNET LASER

Since January 1991, we have performed 79 video-assisted neodymium: yttrium-aluminum-garnet laser resections for pulmonary nodular or interstitial disease. Pathologic examination demonstrated malignancy in 59 patients (32 primary and 27 metastatic), benign nodules in 11, interstitial processes in seven, and granulomatous disease in two. There were 39 men and 40 women with a mean age of 63.4 ± 12.5 years. Thirty-nine patients underwent resection with the neodymium:yttrium-aluminum-garnet laser alone and 40 had lesions resected with a combination of laser and endoscopic stapling. Laser excision was performed for lesions deep in the substance of the lung or on its effaced surface; both are locations that make stapling alone difficult. Fifteen of 32 patients with a diagnosis of primary lung malignancy underwent open anatomic resections. Pulmonary reserves of the other 17 patients were inadequate for further resection. Operative time, duration of chest tube placement, length of hospital stay, and complication rate were compared with those for 72 patients undergoing video-assisted thoracic surgical resection of nodules with staplers alone. Although operative time for laser-assisted procedures was longer ($p < 0.05$), there were no differences in duration of chest tube placement or hospital stay compared with stapled resections. The complication rate for laser-treated cases was not higher than for stapled resections and consisted primarily of air leaks lasting 2 to 7 days. The neodymium:yttrium-aluminum-garnet laser is a safe and precise primary or adjunctive tool for video-assisted thoracic surgical pulmonary resection. **(J THORAC CARDIOVASC SURG 1995;110:363-7)**

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With the advent of video technology, video-assisted thoracic surgery (VATS) offers a minimally invasive operative approach to accomplish general thoracic surgical procedures.[1] One of the most commonly performed operations is nonanatomic pulmonary wedge resection for the diagnosis of indeterminate nodules or localized interstitial disease.[2] Development of reliable endoscopic surgical staplers has made this type of resection possible. Unfortunately, lesions on the flat surface of the lung and those deep within the parenchyma are often not approachable with these stapling devices alone. Our experience[3] and that of others[4-7] in using the neodymium:yttrium-aluminum-garnet (Nd:YAG) laser for wedge and segmental resections through small thoracotomies encouraged us to explore this laser's utility in VATS lung resection.[8-10]

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Patients and methods

From January 1991 to February 1993, the Nd:YAG laser was used as a primary or adjunctive tool to perform VATS pulmonary wedge resections in 79 patients with undiagnosed peripheral pulmonary nodules or localized parenchymal diseases. Forty women and 39 men with a

Table I. *Perioperative variables according to method of video-assisted thoracic surgical resection*

	Laser (n = 39)	*Laser + stapler (n = 40)*	*Stapler (n = 72)*
Operating room time (min)	159.4 ± 70.8	160.4 ± 83.6	83.7 ± 51.3*
Chest tube days	3.3 ± 2.6	4.2 ± 4.8	3.0 ± 1.9
Hospital stay (days)	5.6 ± 2.8	6.7 ± 4.7	5.4 ± 2.8

*$p < 0.0001$, stapler vs laser or laser + stapler.

mean age of 63.4 ± 12.5 years (range 35 to 83 years) underwent VATS resection with the Nd:YAG laser alone (39 patients) or had lesions resected with a combination of Nd:YAG laser and endoscopic stapler (40 patients).

The decision to employ the Nd:YAG laser for resection was made on the basis of the size of the lesion and its location within the lung parenchyma. Lesions ranged in size from 0.4 to 3.8 cm in diameter. In general, Nd:YAG laser resection was performed for lesions deep within the substance of the parenchyma or on the flat surface of the lung where use of the stapler alone was judged to be difficult or impossible without injury to the remaining lung tissue.

The operative time, duration of chest tube placement, and length of hospital stay were recorded for all patients, as were the number and type of postoperative complications. Data for patients undergoing laser-assisted pulmonary resections were compared with similar observations made for a concurrent series of 72 patients whose VATS excisions were performed entirely with endoscopic stapling devices.

Follow-up for patients with a diagnosis of malignancy consisted of an office visit with chest roentgenography at 3-month intervals. A computed tomographic scan was obtained in the early postoperative period (approximately 2 to 3 months after operation) to establish a baseline assessment and was repeated at yearly intervals to assess for local or regional recurrence.

Comparisons between the three groups were made with one-way analysis of variance, except for comparisons of complication rates in which Fisher's Exact Test was performed. A level of $p < 0.05$ was considered significant.

Operative technique. The basic operative approaches to performing VATS procedures has been described by us elsewhere[1] and therefore will be summarized only briefly here, with emphasis on the technique of laser resection. All procedures were performed with the patients under general anesthesia and double-lumen endotracheal intubation, which permitted isolation and collapse of the ipsilateral lung. Skin preparation and draping were identical to techniques used in open thoracotomy procedures; this allowed conversion to formal thoracotomy if necessary.

Careful evaluation of the preoperative computed tomographic scan was essential in planning trocar placement and in reducing the time required to localize the area of lung pathology. In 14 cases, small lesions that were considered difficult to identify were localized before operation with a percutaneous wire technique under computed tomographic direction, similar to that used to localize occult breast lesions.[11]

The first trocar insertion site was usually placed in the sixth intercostal space in the mid-to-posterior axillary line through a small skin incision. Ipsilateral ventilation was stopped and the lung was collapsed. Additional cannulas were placed as necessary to allow complete manipulation and examination of the entire lung, as well as to assist in the resection of the lesion.

Surface lesions were usually identifiable as firm masses that were often stellate in shape. Deeper lesions often produced a bulging contour when the lung was collapsed or when a blunt probe was passed over the surface of the lung. On occasion, these maneuvers failed to localize the lesion. In such cases, direct palpation of the lung through a trocar site placed near the area of interest was successful in identifying the lesion's location. Direct palpation was aided by grasping parts of the lung with an endoscopic or regular clamp introduced through another port and advancing those areas toward the palpating finger.

Once the decision was made to use the Nd:YAG laser (Lasersonics, Inc., Milpitas, Calif.), appropriate safety precautions were implemented. These included the covering of all windows in the operating room and the use of protective eye wear by all personnel.[5, 12, 13] The laser power level was set to between 15 and 40 W, depending on whether contact or noncontact mode was being used. The laser system timing was set to continuous wave. A smoke evacuator system was used during VATS laser procedures to keep the pleural cavity clear of laser plume, which otherwise could have caused a reduction in visibility and necessitated frequent cleaning of the thoracoscope's lens.

When a resection was performed with the Nd:YAG laser as the primary operating tool, a 0.5 to 1.5 cm margin of normal tissue was maintained about the parenchymal lesion. This tissue was grasped with forceps to isolate the lesion and to provide a degree of traction. The resection was begun with the laser in contact mode at a power of 15 to 20 W to score the visceral pleural margin and indurate the first 5 mm of the resection. As the incision was developed, the deeper aspects of the resection were then completed in the defocused noncontact mode with the laser fiber approximately 1 cm from the parenchyma. At this point the power output of the laser was increased to between 35 and 40 W. By adjusting the focal distance of the fiber, parenchymal bronchioles and vessels, which are whiter in color and do not absorb the Nd:YAG wavelength (1064 nm) as readily as the surrounding pulmonary parenchyma, could be skeletonized and clipped before division. Pulmonary parenchymal vessels less than 2 mm in diameter were coagulated and transected with the defocused Nd:YAG laser beam. Resection deep to the lesion was then completed with the laser (n = 39) or by applying an endoscopic stapler (n = 21) across the base. Alternatively, the laser was also used to complete a stapled wedge resection (n = 19) by vaporizing and coagulating across the base of the resection margin be-

Table II. *Postoperative complications after VATS resection*

	Laser (n = 39)	*Laser + stapler (n = 40)*	*Stapler (n = 72)*
Air leak >2 days	4	2	6
Air leak >5 days	1	3	3
Atelectasis	1	2	
Pneumonia	2	1	
Subcutaneous emphysema	1	1	
Supraventricular dysrhythmia		1	1
Intercostal artery laceration	1		1
Death			1
Total complications	11/39	10/40	12/72*

*p not significant.

tween stapled edges when the tissue was too deep or thick to accommodate the jaws of the stapling device.

Smaller specimens, less than 10 mm in diameter, were removed from the pleural cavity with endoscopic forceps through one of the cannulas. Larger specimens were removed with a commercially available endoscopic specimen-retrieval system introduced into the hemithorax. Occasionally, the skin and fascial incision needed a slight (2 to 4 cm) extension to facilitate removal of the specimen from the pleural cavity.

Once the lesion was resected, the remaining lung tissue bed was examined for hemostasis. Small bleeding vessels were coagulated with the defocused laser in a noncontact mode at about 35 W of power to the tissue. The lung was then inflated to check for air leaks. If leaks were present, a more concentrated application of the defocused Nd:YAG beam was sprayed over the sites. We have recently begun to routinely use a biologic glue of thrombin and cryoprecipitate applied over the raw surface of the lung to seal small air leaks and stop parenchymal oozing.

Results

All patients undergoing VATS laser or laser-assisted resection had their lesions completely excised without the need for conversion to open thoracotomy. Lesions ranged in size from 0.4 to 3.8 cm in diameter. Patients found to have benign disease (n = 11) or metastatic malignancy (n = 27) were treated with VATS wedge resection alone. All pulmonary metastasectomies were conducted for diagnostic purposes only or to obtain sufficient tissue for experimental protocol therapies.

Thirty-two patients were found to have primary carcinoma of the lung. Seventeen of these patients had significant impairment in cardiopulmonary reserves, with forced expiratory volume in 1 second values ranging from 450 to 800 cc and single-breath diffusing capacity measurements of less than 20%. These individuals were not considered candidates for a lobectomy, and wedge resection was therefore the definitive surgical therapy. Eleven patients underwent thoracoscopic mediastinal lymph node sampling at the time of resection. The remaining six individuals, all with squamous cell carcinomas, had their disease staged according to preoperative computed tomographic scans alone. Many of these patients received local adjuvant radiotherapy. Fifteen patients were believed to have adequate pulmonary functional reserves and underwent more extended resection with intraoperative lymph node sampling while under the same general anesthesia. Twelve patients were managed by open (six) or video-assisted (six) lobectomy. Three patients underwent formal segmentectomy after conversion of their operation to lateral muscle-sparing thoracotomies.

Operative time averaged 159 minutes for laser excision alone and 160 minutes when the laser was used as an adjunct to stapled resection (Table I). As expected, operative time for these procedures was significantly longer ($p < 0.0001$) than for resections accomplished with staplers alone (84 minutes). There were no significant differences among groups, however, with respect to postoperative chest tube duration or length of hospital stay (Table I).

Postoperative complications after Nd:YAG laser pulmonary resection were not significantly higher than for patients undergoing stapled resection alone (Table II). Four patients required continued tube thoracostomy drainage for 5 to 16 days, but none required a second surgical intervention. Pneumonia was successfully managed in three patients with an appropriate course of systemic antibiotics. One patient required reexploration during the immediate postoperative period to evacuate a localized hemothorax resulting from trocar injury to an intercostal artery. There were no postoperative deaths among patients in whom laser resection was performed.

To date there has been one documented local recurrence of carcinoma among patients who underwent VATS laser resection. This occurred 18 months after resection of a bronchogenic carcinoma. This patient was judged to have insufficient pulmonary reserves to tolerate further resection on the basis of pulmonary function and exercise oximetry testing. No adjuvant therapy was given.

Discussion

Patients who are candidates for VATS procedures include those with undiagnosed pulmonary parenchymal lesions and patients with known primary bronchogenic malignancies who are documented to have inadequate cardiopulmonary reserve. These latter individuals comprise a group of high-risk patients for whom nonanatomic resection is considered the most appropriate procedure. Patients requiring diagnosis of possible pulmonary metastases from known visceral malignancies are also candidates for VATS excisional biopsy. In the absence of definitive results of percutaneous aspiration biopsy, the standard surgical therapy has been to perform a wedge or other resection through an open thoracotomy. With the advent of video-assisted technology, VATS resection can be accomplished with minimal complications.[2]

The Nd:YAG laser is the most versatile laser for general thoracic surgical use.[3, 7] Nd:YAG laser resection during open thoracotomy has proved efficacious in the excision of lesions from patients with marginal pulmonary function.[4, 5] In VATS, the laser can be a valuable asset. It is most useful in selected patients as a tool for resection of deeply seated pulmonary lesions or lesions on the flat surface of the lung. Many nodules in these locations cannot safely be resected with endoscopic stapling devices without the risk of tearing the pulmonary parenchyma, deforming the remaining lung, or causing a late staple line dehiscence from application across thick tissue. The Nd:YAG laser can also be used in conjunction with endoscopic staplers to facilitate VATS pulmonary resection and minimize the amount of tissue to be excised.

Excision of pulmonary nodules by precision electrocautery has been advocated by some,[14] primarily in open procedures. We have found this method to be a less satisfactory tool for VATS resection. Electrocautery relies on continuous contact to accomplish resection, which reduces the ability to identify vessels and bronchioles as they appear during the resection. Electrocautery is also less reliable in sealing parenchymal air leaks. Argon beam coagulation may be useful for achieving superficial hemostasis, but it is totally inadequate for pulmonary resection.

During VATS resection, we prefer to use the laser in a noncontact, "free beam" mode in which the laser fiber is directed at the tissue from a distance of 1 to 2 cm. Adjustment of the focal distance determines the power density at the tissue surface, which ultimately determines whether the beam will primarily cut or coagulate. The laser energy can also be delivered directly to the tissue by contact with a specially designed chamfer-tipped fiber. This allows precise cutting with minimal thermal damage to surrounding structures and is the method we use to outline the proposed resection margin.

In this report, we document our experience with the use of Nd:YAG laser for the resection of nodular pulmonary disease. Fewer than 20% of our cases of VATS wedge excision have involved laser resection. In many of these cases, however, use of the laser permitted a more limited resection than would otherwise have been possible in patients with benign or metastatic disease. For patients with primary malignancies, excisional biopsy was performed on these indeterminate nodules; this was followed by more definitive anatomic resection in patients with sufficient pulmonary reserves.

The laser has proved a safe primary or adjunctive tool, with no increased risk when compared with stapled resection alone in similar patients. We recommend the selective use of this modality when available for the excisional biopsy of indeterminate pulmonary nodules. Definitive management of these lesions is based on frozen-section diagnosis and the patient's cardiopulmonary reserves.

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